Express Mail Label #EM63994: "4US
Date of Deposit: October 1995

DIFFUSELY REFLECTIVE DISPLAY CELL

Technical Field

This invention relates to displays. More particularly, it relates to diffusely reflective displays which produce an image having the appearance of print on paper.

Background Art

The front of screen requirement of a reflective display is that the display should reflect light towards the viewer over the entire specified range of viewing angles under all illumination conditions. In other words reflective displays must be diffusely reflective.

Some display transducers operate effectively only by specular reflection of light. Others may scatter light over a narrow angular range about the specular reflection direction.

A display transducer modulates the reflection or scattering of light from a display. Several transducers under consideration for paper-like displays (PLDs) operate by switching from a transparent to a light scattering state. If these transducers do not scatter light over an adequately wide angle to meet the PLD front-of-screen (FOS) requirements, their FOS properties must be improved.

It would also be desirable to enable PLDs to be made using a second class of transducer; those which operate in specular reflection mode. This class includes Bragg-reflecting Liquid Crystals, laterally-switched electrophoresis cells, and electrically switchable Bragg stacks (variable index distributed mirrors).

There are existing methods by which scattering properties can be conferred on such transducers, but none of them offers the performance required for PLDs. For example;

A. An external diffusely reflecting mirror has unacceptable parallax.

B. An internal diffusely reflecting mirror is difficult to fabricate, and performs less well than desired because of total internal reflection losses at the front window.

C. A conventional diffusing element placed on the front substrate of the display exhibits high back-scatter, which degrades contrast to an unacceptable extent.

A specific example of a prior art approach is the use of a diffusely reflective mirror external to the display cell, which has transparent electrodes. Parallax between the primary image formed in the display cell and the secondary image formed by the reflector makes this approach unsuitable for high resolution displays which are viewed more than a few degrees off-normal.

Another specific example of prior art is the use of a rough, diffusely reflective metallic pixel electrode. The rough surface of the electrode may disrupt the required structure of the liquid crystal layer, and such an electrode will have low reflectivity because of losses due to multiple reflections at the rough metal surface.

Summary of the Invention

This invention is directed to a general means by which the transducers described above can be incorporated into a diffusely reflecting display which scatters light over a wide angle, making it suitable to be viewed under a wide range of illumination and viewing conditions.

The key idea in this invention is to incorporate a diffusing element (holographic or surface relief) internally into the display cell either on to the front or rear substrate of the display. Thus the light incident on the display will be scattered once by the diffuser over a solid angle θ. It will then be reflected at the pixel surface and be scattered a second time over an angle of approximately 2θ.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic cross sectional view illustrating the problem of specular reflection in a prior art display.

Fig. 2 is a cross sectional schematic view of a first embodiment of the present invention.

Fig. 3 is a graph of the intensity of light as a function of angle scattered by the display of Fig. 2 and as compared to a Lambertian diffuser wherein both are illuminated at normal incidence.

Fig. 4 is a cross sectional schematic view of a second embodiment of the present invention.

Detailed Description of the Preferred Embodiments

Referring to Fig. 1, a conventional display 10 wherein specular reflection of light occurs is illustrated. Display 10 has a front substrate 12 coated with a transparent common electrode 13 and a rear substrate 14. A plurality of reflective pixel electrodes 16 are formed on rear substrate 14 to selectively activate a material 18 disposed in the space between front substrate 12 and rear substrate 14 in response to an electric field created upon application of a voltage between pixel 16 electrode and common electrode 13. Material 18 may be a liquid crystal, an electrochromic material, or an electrophoretic

material. If material 18 is a liquid crystal material, it may be any of several different types, including PDLC, PSCT or dye guest-host material.

Display 10 is virtually inoperative as a reflective direct view device. With an observer positioned at normal incidence, a ray of light 20 at other than normal incidence will not be reflected back to the observer 22. Further, if a ray of light is at normal incidence, the observer will see the light source reflected in the display and will not perceive the image which is intended to be displayed. In other words the image contrast ratio as viewed by the observer will be virtually 1 (no contrast).

Referring to Fig. 2, in accordance with the invention, a display 26 is similar in general structure to the display of Fig. 1, but includes, on the lower surface of front substrate 12 a diffuser 28. Diffuser 28 should have the property of providing low back-scatter; that is most of the light should be diffused and transmitted rather than reflected by the diffuser. Diffuser 28 is preferably a volume holographic diffuser manufactured by Polaroid Corp. or a surface relief holographic diffuser of the type manufactured by Rochester Photonics Corp. although other materials having low back-scatter properties may also be used. If the diffuser is of the surface relief type, it may be made by surface replication or by photolithographic methods. If it is a volume hologram, it can be made by other standard manufacturing techniques.

In Fig. 2, a ray of light 30 travels through front substrate 12 and is scattered by diffuser 28. Because of the low back scatter properties, virtually all of the light is diffused into the active material 18 where it is either transmitted, absorbed or scattered in accordance with the electric field supplied between common electrode 13 and pixel electrode 16. Light traveling through active material 18 is specularly reflected by pixel electrode 16 and again travels through material 18. The light then again continues on to diffuser 28 where it is again scattered through a relatively large range of angles. Thus, the observer 22 can view an image with excellent contrast regardless of the illumination angle. This superior performance is achieved as a result of diffuser 28 being used twice; first upon entry of

light, and then upon its exit toward the observer.

Of course, if a viewer is positioned at the specular reflection angle of ray 30 from the front surface, the viewer will see some reflection of the light source. However, by merely changing position, this reflection can be avoided. In addition, an anti-reflection coating on the upper surface of front substrate 12 will assist in reducing the intensity of any such reflections, as is well known in the art.

In Fig. 3, a graph of the intensity of light as a function of angle scattered by the display of Fig. 2, is compared to that of a Lambertian diffuser wherein both are illuminated at normal incidence. The Lambertian diffuser would provide uniform illumination over a range of 0 degrees to at least 70 degrees. The invention provides fairly uniform scattering as a function of angle except close to normal incidence. The best result are obtained in terms of uniform illumination when the diffuser is in a material having a low index of refraction, although the results may be acceptable for many applications, even if the index of refraction of the material in which the diffuser is immersed is as high as 1.41. By increasing the index of refraction of the material from which the diffuser is made, improved performance may be obtained with immersion media of higher refractive index.

In the embodiment of the invention illustrated in Fig. 4, like reference numerals refer to the same elements as those in Fig. 1 and Fig. 2. In Fig. 4, the diffuser 34, which may be similar to the one used in the embodiment of the invention illustrated in Fig. 2, is placed directly over the reflective pixel electrode 16. The diffuser 34 is covered by a planarizing layer 36 which is in contact with the active material 18. Light 38 entering the cell is diffused once on impinging upon the diffusion layer 34. The diffused light is reflected by pixel electrode 16. This diffuser light is again diffused by diffuser 34. The light then emerges from planarizing layer 36. Thus, the embodiment of the invention illustrated in Fig. 4 also uses the diffuser to diffuse the light 38 twice. Further, as in the embodiment illustrated in Fig. 2, parallax problems such as those caused by placing the diffuser outside of front substrate 12 of the display are avoided. Thus, the structure of Fig. 4 also

produces a high contrast display which may be viewed through a large range of angles and simulates the appearance of a paper-like display.

Conventional diffusers may achieve similar scattering properties, but scatter a significant fraction of the incident light in the backward direction. The back-scattered light adds to the light reflected from the pixel for both the dark and light states and degrades contrast unacceptably. As little as 10 per cent backscatter, which is a relatively low value for a conventional diffuser, would degrade intrinsic contrast ratios of 100:1 and 10:1 to 9:1 and 5:1 respectively. Thus, the low backscatter achievable with holographic diffusers is key to the best mode for implementation of the invention. The backscattered component of the light should only be approximately 3.5 per cent or less of the total incident light. Preferably, it should be as low as 0.3 per cent.

It is also preferable that the diffuser achieve scattering angle at or above the Lambertian value, out to 45 degrees.